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(71) Applicant(s)
Teikoku Piston Ring Co Ltd

(Incorporated in Japan)

9-9 Yaeseu 1-chome, Chuo-ku, Tokyo, Japan

(72) Inventor(s)
Hiroto Fukutome
Nobuyuki Yamashita
Shoji Tanaka

(74) Agent and/or Address for Service
Frank B Dehn & Co
179 Queen Victoria Street, LONDON, EC4V 4EL,
United Kingdom

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WPI

(54) Piston ring

(57) A film (16, 17) is formed by physical vapor deposition on the outer circumferential sliding surface (18, 19) of a piston ring. The film (16, 17) is comprised of a hard layer (20, 21) figs 2, 3, a gradient layer (22, 23) and an initial break-in layer (24, 25) formed in layers towards the piston ring surface. The hard layer (20, 21) is a Cr_2N layer or a layer of a mixture of Cr_2N and Cr. The initial break-in layer (24, 25) is a layer made of chromium with nitrogen included in a solid solution state and has a Vickers hardness of 300 to 800. The gradient layer (22, 23) is formed between the hard layer (20, 21) and the initial break-in layer (24, 25) in the physical vapor deposition process forming the hard layer (20, 21) and the initial break-in layer (24, 25). The gradient layer (22, 23) has the nitrogen concentration decreasing towards the piston ring surface.

FIG.1

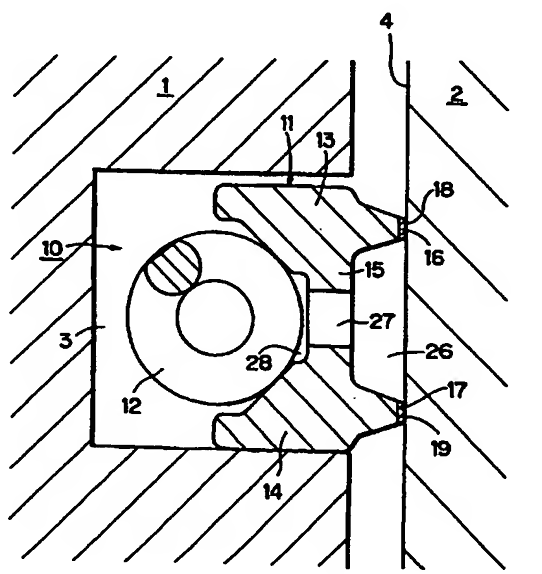

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FIG.1

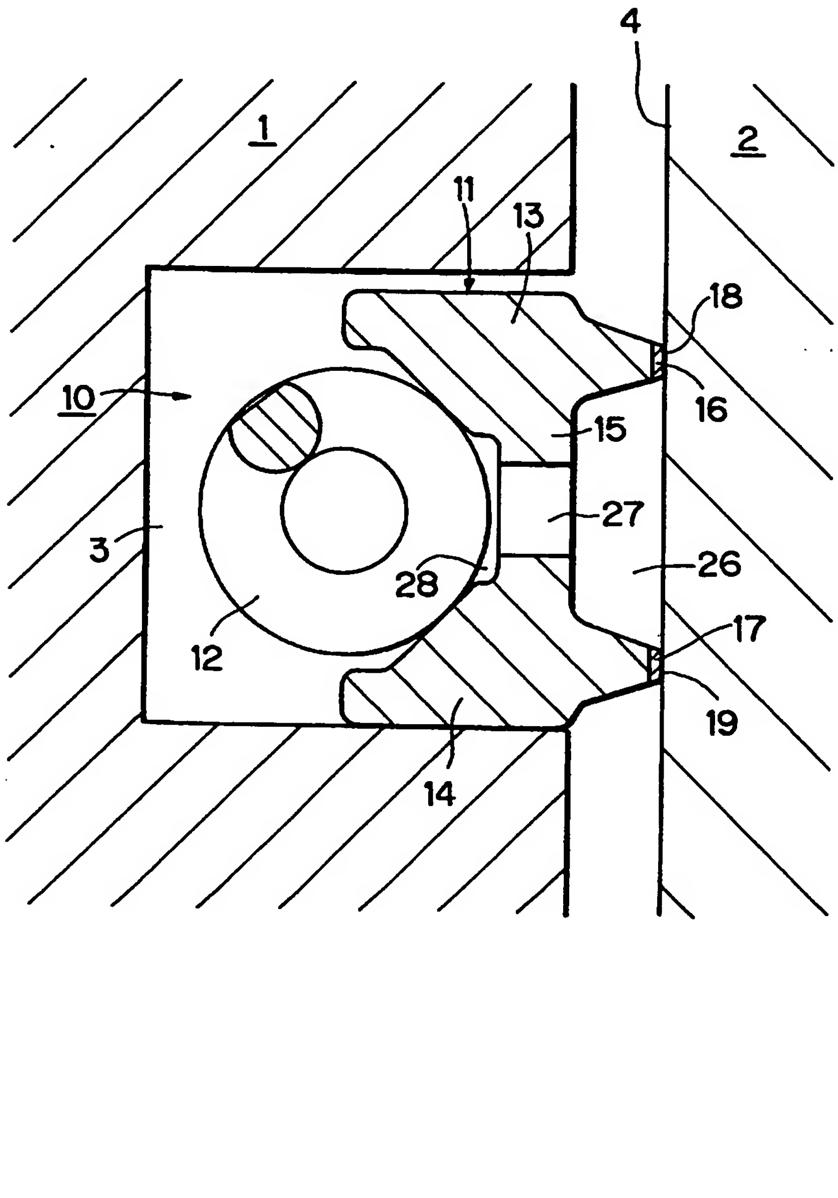

FIG.2

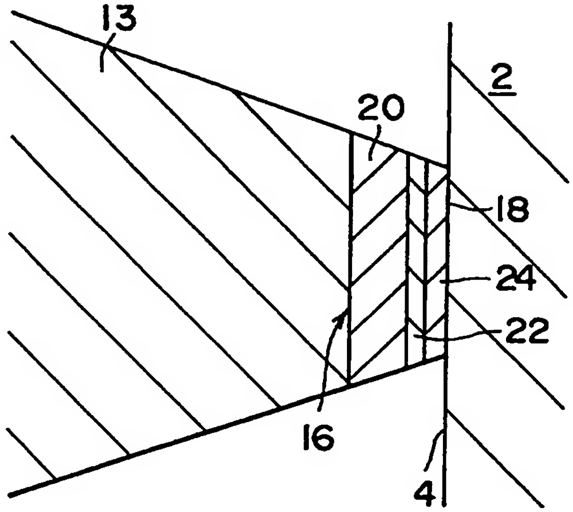

FIG.3

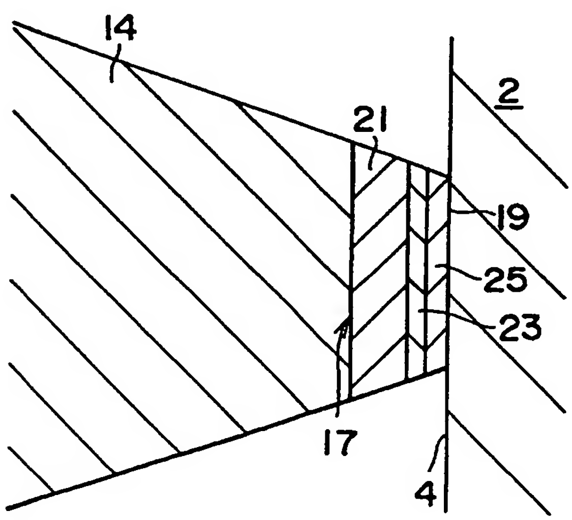

FIG.4

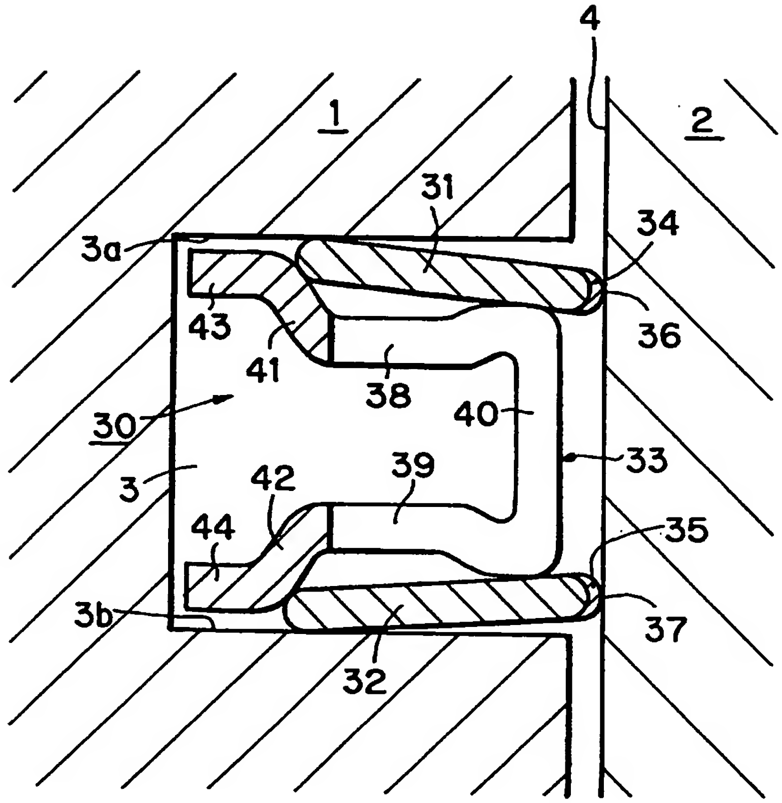

FIG.5

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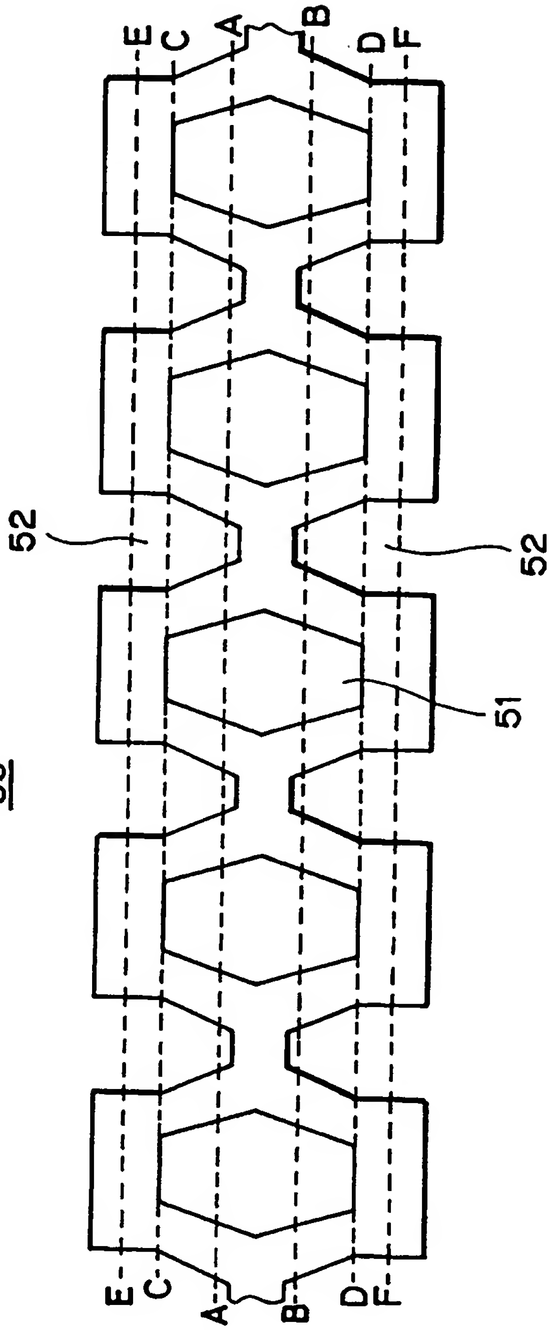


FIG.6

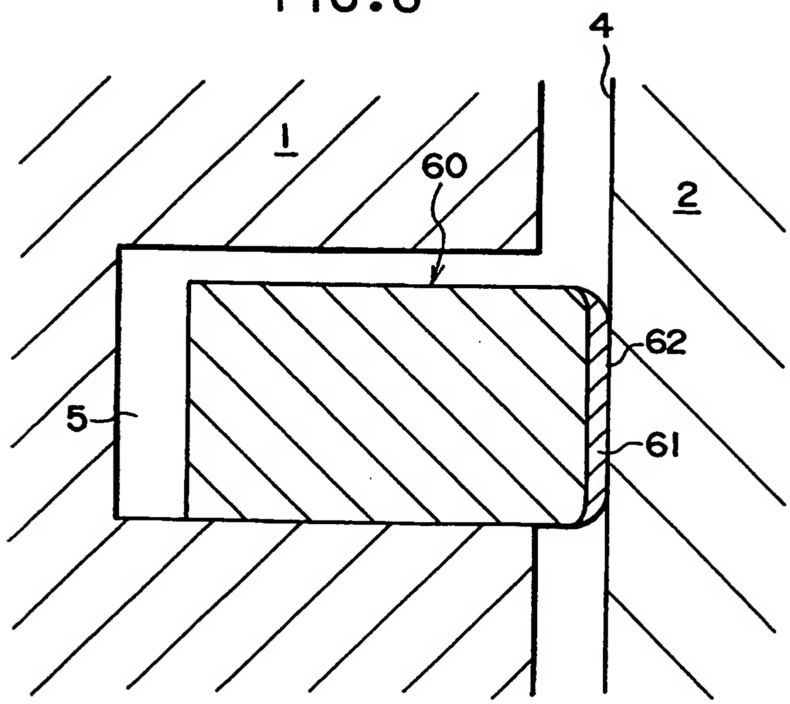


FIG.7

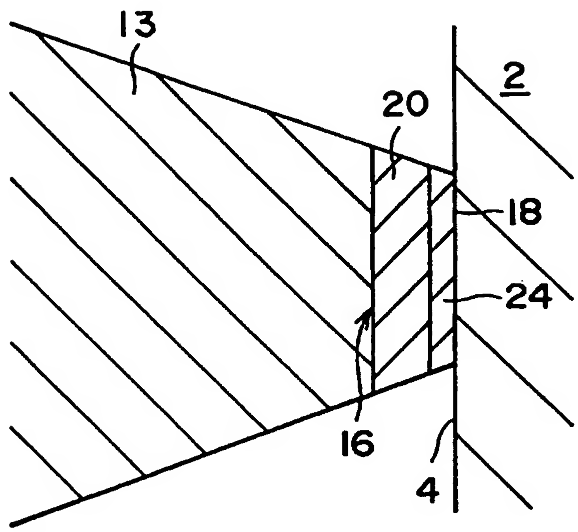
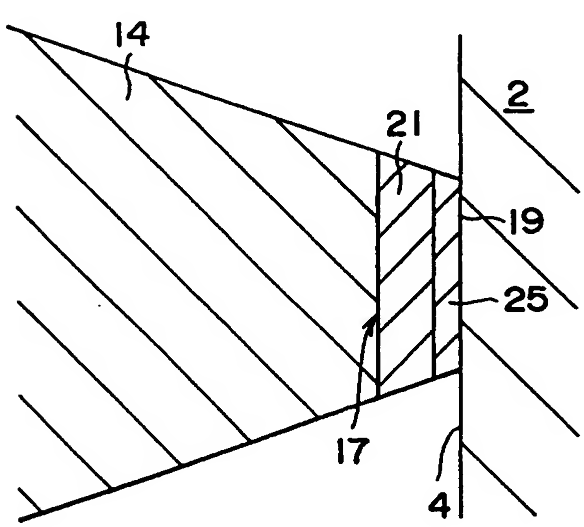


FIG.8



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TITLE OF THE INVENTION

PISTON RING

This invention relates to piston rings fitted on pistons used in internal combustion engines.

In recent years the load applied to piston rings has steadily increased due to higher engine performance and higher engine output. Efforts to improve oil consumption tended towards reducing the oil ring axial width to increase the function of oil control, with the result that high surface pressure occurred on the sliding surface making contact with the inner circumferential surface of the cylinder, thus making sliding conditions more severe than ever before. Also, in efforts to reduce blow-bye gas, the compression ring axial width was reduced to improve conformability with the piston, with the result that high surface pressure occurred on the sliding surface making contact with the inner circumferential surface of the cylinder, thus making sliding conditions more severe than ever before. Thus, harsher demands have been created on the piston ring.

Therefore, coating the outer circumferential sliding surface of the piston ring with a film of Cr_2N (Japanese Patent Laid-open No. 1-156461) or a film of mixture of Cr_2N

and Cr (Japanes Patent Publication No. 6-25597) has been proposed. Also, a method is known (in Japanese Patent Laid-open No. 62-228648) for forming a CrN film ov r a film of a mixture of Cr_2N and Cr.

Preferably the initial break-in period of the sliding surface ends quickly with wear on the sliding surface progressing no further in order to reduce oil consumption and blow-bye gas. However, though these films of the prior art were effective against wear, the initial break-in characteristic was inadequate and time was required to obtain a state where the cylinder and piston ring conformed well to each other.

A composite plating of nickel-phosphorus alloy is available as a means to improve the initial break-in characteristic. However, this process was of low productivity because continuous processing was not possible after forming of the hard film by physical vapor deposition.

This invention has the object of providing a piston ring with superior initial break-in characteristics and wear resistance, and that is also easy to manufacture.

The piston ring of this invention has a hard layer of Cr_2N or a hard layer of a mixture of Cr_2N and Cr formed by physical vapor deposition on the outer circumferential sliding surface of the piston ring and an initial break-in layer formed by physical vapor deposition on the hard layer. The initial break-in layer is a layer made of chromium with nitrogen included in a solid solution state and has a

Vickers hardness of HV 300 to 800. Th initial break-in layer has preferably a nitrogen content of 0.5 to 2.0 percent by weight.

A gradient layer by physical vapor deposition is preferably formed between the hard layer and the initial break-in layer. The gradient layer is formed between the hard layer and the initial break-in layer in the physical vapor deposition process forming the hard layer and the initial break-in layer. The gradient layer has the nitrogen concentration decreasing consecutively or at intervals towards the surface of the piston ring.

When the hard layer is comprised of Cr_2N, the gradient layer is comprised of Cr_2N, Cr_2N + Cr, and Cr (with nitrogen included in a solid solution state) or comprised of Cr_2N + Cr, and Cr (with nitrogen included in a solid solution state) formed in layers towards the ring surface, and has the nitrogen concentration decreasing towards the ring surface. When the hard layer is comprised of a mixture of Cr_2N and Cr, the gradient layer is comprised of Cr_2N + Cr, and Cr (with nitrogen included in a solid solution state) formed in layers towards the ring surface or comprised of Cr (with nitrogen included in a solid solution state), and has the nitrogen concentration decreasing towards the ring surface.

The initial break-in layer has a specified hardness of HV300 to 800 compared to an ordinary chromium layer on account of nitrogen included in a solid solution state within the chromium. Thus, wearing off of the initial

break-in layer prior to break-in is few, and break-in is completed within a short tim .

The gradient layer has a hardness in a range between that of the hard layer and the initial break-in layer and serves to supplement the initial break-in layer. The gradient layer has a higher degree of hardness and is resistant to wear as compared to the initial break-in layer. In the initial break-in layer, wear occurs rapidly at both high surface pressure and low surface pressure, but in the gradient layer wear progresses rapidly at high surface pressure yet shows little wear progression at low surface pressure. Accordingly, when the gradient layer begins to appear at worn locations while the initial break-in layer still has no effect, the exposed portions are sliding surfaces under high surface pressure, so that wear progresses and break-in is completed within a short time. Further, on portions where the ring has been broken in prior to wearing off of the initial break-in layer, the sliding surfaces are under low surface pressure, so that there is little wear progression on the gradient layer and increase of the ring gap is prevented.

Increase of the ring gap after the each layer has worn off can be greatly limited and oil consumption and blow-bye gas also greatly suppressed by making the initial break-in layer within 10 micrometers and the gradient layer within 5 micrometers.

The films for the piston ring are easy to manufacture since the initial break-in layer, the gradient layer and the

hard layer are all formed by consecutive processing with physical vapor deposition.

Various embodiments of the present invention will now described, by way of example, with reference to the accompanying drawings in which:

Fig. 1 is a longitudinal cross sectional view showing a combined oil ring which is fitted in an oil ring groove of the piston inserted into the cylinder in an embodiment of this invention.

Fig. 2 is an enlarged view of the sliding portion of the upper rail for the combined oil ring of Fig. 1.

Fig. 3 is an enlarged view of the sliding portion of the lower rail for the combined oil ring of Fig. 1.

Fig. 4 is a longitudinal cross sectional view showing a combined oil ring which is fitted in an oil ring groove of the piston inserted into the cylinder in another embodiment of this invention.

Fig. 5 is a plan view showing a portion of the material of a spacer expander.

Fig. 6 is a longitudinal cross sectional view showing a compression ring which is fitted in a ring groove of the piston inserted into the cylinder in still another embodiment of this invention.

Fig. 7 is an enlarged view of the sliding portion of the upper rail for the two piece type combined oil ring of

Fig. 1 and shows another example of th film by physical vapor deposition.

Fig. 8 is an enlarged view of th sliding portion of the lower rail for the two piece type combined oil ring of Fig. 1 and shows another example of the film by physical vapor deposition.

Fig. 1 is a longitudinal cross sectional view showing a combined oil ring which is fitted in an oil ring groove of the piston inserted into the cylinder in one preferred embodiment of this invention. Referring now to Fig. 1, a combined oil ring 10 is fitted in an oil ring groove 3 formed on the outer circumferential surface of a piston 1 inside a cylinder 2. The combined oil ring 10 is a two piece type combined oil ring made of steel, and comprised of an oil ring 11 and a coil expander 12.

The oil ring 11 is a steel ring with a gap and formed in a generally I-shape in cross section, and comprises paired upper and lower rails 13 and 14 extending in the circumferential direction and joined together by a thin-walled, straight web portion 15. The outer circumferential surfaces of the upper and lower rails 13 and 14 are formed with films 16 and 17 by physical vapor deposition, and are in contact with the inner circumferential surface 4 of the cylinder 2 and constitute sliding surfaces 18 and 19 to scrape oil from the inner circumferential surface 4 of the cylinder 2. As shown in Fig. 2 and Fig. 3, the films 16 and 17 by physical vapor deposition are respectively comprised

of hard layers 20 and 21, gradient layers 22 and 23, and initial break-in layers 24 and 25 formed in layers towards the piston ring surface. The axial width of respective outer circumferential surface of the upper and lower rails 13 and 14 is 0.4mm or less.

The hard layers 20 and 21 are Cr_2N films or mixed Cr_2N and Cr films. The nitrogen content of the layers is respectively 11 to 17 percent by weight, and the Vicker's hardness of the layers is respectively in the range of HV1300 to HV2000. A maximum thickness of approximately 50 micrometers is sufficient for the hard layers 20 and 21 while a thickness greater than 3 micrometers is preferable for resistance to wear.

The initial break-in layers 24 and 25 are chromium layers with nitrogen of 0.5 to 2.0 percent by weight included in a solid solution state. The initial break-in layers 24 and 25 have a Vickers hardness of HV300 to 800. The initial break-in layers 24 and 25 have a thickness within 10 micrometers.

The gradient layers 22 and 23 are formed between the hard layers 20 and 21 and the initial break-in layers 24 and 25 in the physical vapor deposition process forming the hard layers 20 and 21 and the initial break-in layers 24 and 25. The gradient layers 22 and 23 have the nitrogen concentration decreasing consecutively or at intervals towards the ring surface. The hardness of the gradient layers 22 and 23 is in a range between that of the hard layers 20 and 21 and the initial break-in layers 24 and 25.

The thickness of the gradient layers 22 and 23 is within 5 micrometers.

An outside circumferential groove 26 formed by the web portion 15 and the outside circumferential projections of the upper and lower rails 13 and 14 is an oil receiving groove. The oil on the inner circumferential surface 4 of the cylinder 2 is scraped by the sliding surfaces 18 and 19 of the upper and lower rails 13 and 14, and moves through a plurality of oil holes 27 formed on the web portion 15 at equal intervals along its circumferential direction to the inside circumferential side of the oil ring 11, and further through a plurality of oil drain holes (not shown) formed on the bottom surface 5 of the oil ring groove 3 on the piston 1 down into the oil pan.

The coil expander 12 fits in an inside circumferential groove 28 formed by the inside circumferential projections of the upper and lower rails 13 and 14 and the web portion 15. The coil expander 12 is made of a wire of a circular cross section wound into a coil, the outside cylindrical surface of the coil is then ground, and the coil is formed into a ring. Therefore, the cross section of the wire is a circle with its outside circumferential portion cut off by grinding. Here, the cross-sectional shape of the wire which forms the coil expander 12 is not limited to the one described above but may be circular etc. The coil expander 12 is provided in a compressed state with its paired ends abutting each other to exert an expanding force in the radially outward direction, and apply pressure on the oil ring 11 toward the radially outward direction, so that the

sliding surfces 18 and 19 of the oil ring 11 ar made contact with th inner circumferential surface 4 of the cylinder 2.

Fig. 4 shows another embodiment of this invention and is different from Fig. 1 regarding the combined oil ring. A combined oil ring 30 of this embodiment is a three piece type combined oil ring made of steel, and comprised of a pair of upper and lower side rails 31 and 32 and a spacer expander 33.

The pair of side rails 31 and 32 are steel rings which are annular with a gap, and formed in a rectangular shape in cross section. The outer circumferential surfaces of the side rails 31 and 32 are formed with films 34 and 35 by physical vapor deposition, and are in contact with the inner circumferential surface 4 of the cylinder 2 and constitute sliding surfaces 36 and 37 to scrape oil from the inner circumferential surface 4 of the cylinder 2. The axial width of respective outer circumferential surface of the upper and lower side rails 31 and 32 is 0.6mm or less. The films 34 and 35 by physical vapor deposition are the same coating as the films 16 and 17 by physical vapor deposition formed on the outer circumferential surface of the oil ring 11 for the said two piece type combined steel oil ring 10.

The spacer expander 33 is formed as follows. A material 50 shown in Fig. 5 has a symmetrical shape with respect to the center axis running longitudinally. That is, a thin steel strip is provided with a plurality of tortoise shell-like holes 51, which serve as oil holes and are

equally spaced in a longitudinal direction of the thin steel strip. Substantially V-shaped slits 52 are provided on both sides of th thin steel strip between the holes 51. This material 50 is bent symmetrically. In other words, the material 50 is bent along the bending lines A - A and B - B into a substantially U-shaped cross section. Next, the upper and lower end portions are bent along the bending lines C - C and D - D to stand obliquely, and then the edges of the upper and lower standing portions are bent horizontally along the bending lines E - E and F - F. After bending the material 50 as explained above, and performing the annular forming step, the cutting step and surface treatment step, the fabrication of the spacer expander 33 is complete.

This spacer expander 33 is composed of a plurality of periodic elements linked together peripherally and having a substantially U-shaped cross section. Each of these periodic elements has a pair of horizontal upper and lower portions 38 and 39, and an upright portion 40 connecting these upper and lower portions 38 and 39. Side rail pressing portions 41 and 42 are formed respectively obliquely facing inwards radially at the inner circumference of the upper portion 38 and lower portion 39. At the inner circumference of each of the side rail pressing portions 41 and 42, are inner portions 43 and 44 extending horizontally to the inner radial direction. Oil holes are formed in the upper portion 38, the upright portion 40 and the lower portion 39.

The spacer expander 33 is provided in the oil ring groove 3 of the piston 1 in a compr ssed stat with the paired ends abutting each other to exert an expanding force in outward radially. The pair of side rails 31 and 32 are supported separately above and below (axially) by the upper and lower portions 38 and 39. The upper and lower side rail pressing portions 41 and 42 apply pressure on the respective inner circumferential surfaces of the pair of side rails 31 and 32, so that the respective sliding surfaces 36 and 37 of the side rails 31 and 32 are made contact with the inner circumferential surface 4 of the cylinder 2, and the inner circumferential ends of the side rails 31 and 32 are made contact with the side surfaces 3a and 3b of the oil ring groove 3.

The oil on the inner circumferential surface 4 of the cylinder 2 is scraped by the sliding surfaces 36 and 37 of the upper and lower side rails 31 and 32, and moves through a plurality of oil holes formed on the spacer expander 33 to the inside circumferential side, and further through a plurality of oil drain holes (not shown) formed on the bottom surface 5 of the oil ring groove 3 on the piston 1 down into the oil pan.

Fig. 6 shows still another embodiment of this invention. This embodiment is different from the above-mentioned two embodiments in that the piston ring is a compression ring.

A compression ring 60 is a steel ring which has a rectangular shape in cross section and has a barrel face.

The outer circumferential surface of the compression ring 60 is formed with a film 61 by physical vapor deposition, and constitutes a sliding surface 62 which makes contact with the inner circumferential surface 4 of the cylinder 2. The axial width of the outer circumferential surface of the compression ring 60 is 0.6mm or less. The film 61 by physical vapor deposition is the same coating as the films 16 and 17 by physical vapor deposition formed on the outer circumferential surface of the oil ring 11 for the said two piece type combined steel oil ring 10.

In the three embodiments of this invention, films by physical vapor deposition have respectively a hard layer, a gradient layer, and an initial break-in layer, however a two layer structure can instead be used consisting of a hard layer and an initial break-in layer yet no gradient layer. Fig. 7 and Fig. 8 show examples of forming on the outer circumferential surfaces of the upper and lower rails 13 and 14 of the oil rig 11 for the two piece type combined steel oil ring 10.

In the above embodiments, a gas nitrided layer is formed beneath the films by physical vapor deposition.

Further, in the above embodiments, besides ion plating, the physical vapor deposition can be performed by vacuum deposition or sputtering, etc.

The oil consumption tests performed to verify the effect of the invention will be explained next.

An arc ion plating apparatus was used to form the film by physical vapor deposition on the outer circumferential surfaces of the upper and lower rails 13 and 14 of the oil ring 11 for

the two piece type combined ste 1 oil ring 10 d scribed in the embodiment and oil consumption tested whil mounted in a test apparatus. Gas nitriding treatment was performed prior to physical vapor deposition on the outer circumferential surfaces.

(1) Forming conditions for film by physical vapor deposition

Vacuum intensity within processing chamber: 10^{-5} to 10^{-6}Torr

Evaporating source : Cr

Reactive gas : Nitrogen gas

Bias voltage : 20 volts (constant)

(Comparative example 1)

Pressure within processing chamber after nitrogen gas inflow : 2mTorr

Deposition rate : 2.7nm/s

Deposition time: 3 hours, processing performed by arc ion plating.

(Comparative example 2)

Only gas nitriding was performed with no arc ion plating.

(Comparative example 3)

(1) Pressure within processing chamber after nitrogen gas inflow : 2mTorr

Deposition rate : 2.7nm/s

Deposition time: 4 hours, processing performed by arc ion plating.

(2) Continuous arc ion plating processing was performed in the same chamber, maintaining the same deposition rate and gradually reducing the nitrogen gas inflow (depressurized to 0.05mTorr in 30 minutes).

(3) Arc ion plating processing was performed for 1 hour at the same deposition rate, at the final pressurized state (0.05mTorr) in (2) above.

(Comparative example 4)

(1) Pressure within processing chamber after nitrogen gas

inflow :	2mTorr
Deposition rate :	2.7nm/s
Deposition time:	4 hours, processing performed by arc ion plating.

(2) Continuous arc ion plating processing was performed in the same chamber, maintaining the same deposition rate and gradually reducing the nitrogen gas inflow (depressurized to 0.9mTorr in 30 minutes).

(3) Arc ion plating processing was performed for 1 hour at the same deposition rate, at the final pressurized state (0.9mTorr) in (2) above.

(Embodiment 1)

(1) Pressure within processing chamber after nitrogen gas

inflow :	2mTorr
Deposition rate :	2.7nm/s
Deposition time:	4 hours, processing performed by arc ion plating.

(2) In the identical processing chamber, the nitrogen gas inflow was reduced to 0.6mTorr within several seconds.

(3) Arc ion plating processing was performed for 1 hour at the same deposition rate, at the same pressure setting (0.6mTorr) as in (2) above.

(Embodiment 2)

(1) Pressure within processing chamber after nitrogen gas

inflow :	2mTorr
Deposition rate :	2.7nm/s
Deposition time:	4 hours, processing performed by arc ion plating.

(2) Continuous arc ion plating processing was performed in the same chamber, maintaining the same deposition rate and gradually reducing the nitrogen gas inflow (depressurized to 0.1mTorr in 30 minutes).

(3) Arc ion plating processing was performed for 1 hour at the same deposition rate, at the final pressurized state (0.1mTorr) in (2) above.

(Embodiment 3)

(1) Pressure within processing chamber after nitrogen gas

inflow :	2mTorr
Deposition rate :	2.7nm/s
Deposition time:	4 hours, processing performed by arc ion plating.

(2) Continuous arc ion plating processing was performed in the same chamber, maintaining the same deposition rate and

gradually reducing the nitrogen gas inflow (depressurized to 0.6mTorr in 30 minutes).

(3) Arc ion plating proc ssing was performed for 1 hour at the same deposition rate, at the final pressurized state (0.6mTorr) in (2) above.

(Embodiment 4)

(1) Pressure within processing chamber after nitrogen gas

inflow :	2mTorr
Deposition rate :	2.7nm/s
Deposition time:	4 hours, processing performed by arc ion plating.

(2) Continuous arc ion plating processing was performed in the same chamber, maintaining the same deposition rate and gradually reducing the nitrogen gas inflow (depressurized to 0.8mTorr in 30 minutes).

(3) Arc ion plating processing was performed for 1 hour at the same deposition rate, at the final pressurized state (0.8mTorr) in (2) above.

Table 1 shows the composition of the film by physical vapor deposition and the hardness of the initial break-in layer.

Table 1

Nitrogen content: percent by weight

	No	Film by physical vapor deposition (or gas nitriding)	Hardness of Initial break-in layer (HV)
Comparative Example	1	Cr_2N(N:15%)	-
	2	Gas nitriding	-
	3	Cr_2N(N:15%) + gradient layer + Cr(N:0.1%)	270
	4	Cr_2N(N:15%) + gradient layer + Cr(N:2.5%)	850
Embodiment	1	Cr_2N(N:15%) + Cr(N:1.7%)	600
	2	Cr_2N(N:15%) + gradient layer + Cr(N:0.5%)	300
	3	Cr_2N(N:15%) + gradient layer + Cr(N:1.7%)	600
	4	Cr_2N(N:15%) + gradient layer + Cr(N:2.0%)	800

Note 1: The gradient layer is comprised of Cr_2N, Cr_2N+Cr, and Cr (with nitrogen included in a solid solution state) arranged in layers towards the surface of the ring, and has a nitrogen concentration decreasing towards the surface of the ring.

(2) Engine test conditions

The combined oil ring was mounted in a four cylinder gasoline engine having a cylinder bore of Ø75mm. During a

250 hour durability test under full load, the oil consumption in grams per hour after one hour of (initial) operation and after 250 hours of (durability) operation was measured.

Test results are shown in Table 2.

Table 2

	No.	Oil Consumption (g/hr)	
		After Initial Operation	After Durability Operation
Comparative Example	1	53.5	28.3
	2	51.6	35.1
	3	48.7	27.8
	4	49.1	28.2
Embodiment	1	34.2	29.5
	2	25.6	26.5
	3	23.3	26.4
	4	24.8	26.1

As can be clearly seen from Table 2, the initial break-in characteristics of the hard film (Cr_2N) and gas nitrided layer in comparative examples 1 and 2 are unsatisfactory. Also, even if the same layer structure as this invention was used, in th initial break-in layers (chromium with nitrog n

included in a solid solution state) of comparative examples 3 and 4 having a respective hardness of HV270 and HV850, the initial break-in characteristics were not much improved compared to gas nitrided layer and hard film (Cr_2N).

In contrast however, the film of this invention having no gradient layer, with a hardness of HV600 in the first embodiment in the initial break-in layer (chromium with nitrogen included in a solid solution state) showed improved initial break-in characteristics compared to gas nitrided layer and hard film (Cr_2N). Further, the film of this invention having a gradient layer, with a hardness of HV300 to 800 in the embodiments 2, 3 and 4 in the initial break-in layer (chromium with nitrogen included in a solid solution state) showed further improved initial break-in characteristics.

The oil consumption results after the durability tests were all satisfactory.

Although the present invention has been described with referece to the preferred embodiments, it is apparent that the present invention is not limited to the aforesaid preferred embodiments, but various modification can be attained without departing from its scope as defined by the claims.

C L A I M S :

1. A piston ring having a hard layer of Cr_2N or a hard layer of a mixture of Cr_2N and Cr formed by physical vapor deposition on the outer circumferential sliding surface of said piston ring and an initial break-in layer formed by physical vapor deposition on said hard layer, said initial break-in layer being a layer made of chromium with nitrogen included in a solid solution state and having a Vickers hardness of 300 to 800.

2. A piston ring as claimed in claim 1, in which said initial break-in layer has a nitrogen content of 0.5 to 2.0 percent by weight.

3. A piston ring as claimed in claim 1 or claim 2, in which said initial break-in layer has a thickness within 10 micrometers.

4. A piston ring as claimed in any one of claims 1 to 3, in which a gradient layer is formed between said hard layer and said initial break-in layer in the physical vapor deposition process forming said hard layer and said initial break-in layer, and has the nitrogen concentration decreasing towards the piston ring surface.

5. A piston ring as claimed in claim 4, in which said gradient layer has a thickness within 5 micrometers.

6. A piston ring as claimed in any one of claims 1 to 5, in which said piston ring is a combined oil ring comprising one oil ring and one coil expander, and said outer circumferential sliding surface formed with said layers is the outer circumferential sliding surface of said oil ring.

7. A piston ring as claimed in any one of claims 1 to 5, in which said piston ring is a combined oil ring comprising two side rails and one spacer expander, and said outer circumferential sliding surface formed with said layers is the outer circumferential sliding surface of said side rail.

8. A piston ring as claimed in any one of claims 1 to 5, in which said piston ring is a compression ring.

9. A piston ring substantially as hereinbefore described with reference to the accompanying drawings.

The Patent Office

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Applicati n No: GB 9713243.5
Claims searched: 1-9

Examiner: R L Williams
Date of search: 23 September 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): F2T

Int Cl (Ed.6): F02F 5/00 F16J 9/26,9/28

Other: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 2,294,950 A	Kabushiki Kaisha Riken	1
A	GB 1,330,967	Dana Coperation	1
A	US 5,316,321	M Ishida et al	1

X Document indicating lack of novelty or inventive step
Y Document indicating lack of inventive step if combined with one or more other documents of same category.
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